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LOCKHEED MARTIN DEFENSE SYSTEMS
PITTSFIELD, MASSACHUSETTS

CLOSED LOOP AQUEOUS CLEANING OF MECHANICAL PARTS

TOXICS USE REDUCTION INSTITUTE
CLEANER TECHNOLOGY DEMONSTRATION SITES PROGRAM

Technical Report No. 33 1996

University of Massachusetts Lowell

Lockheed Martin Defense Systems
Pittsfield, Massachusetts

Closed Loop Aqueous Cleaning Of Mechanical Parts

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1996

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Preface

In its 1996 fiscal year, the Massachusetts Toxics Use Reduction Institute launched the first Cleaner Technology Demonstration Sites Program. The goal of the program was to promote the adoption of cleaner technologies by Massachusetts industry. Five companies were selected as demonstration sites to showcase the implementation of technologies that embrace the concepts and principles of toxics use reduction. The program, which included a series of visits to the facilities and related presentations and publications, allowed individuals and firms to observe and assess their value first-hand. Site visits were open to industry, environmental groups, community groups, the media and others.

Associate sponsors of the program included the Massachusetts Office of Technical Assistance for Toxics Use Reduction, the Executive Office of Environmental Affairs, the Department of Environmental Protection, the Environmental Protection Agency of New England, and the Associated Industries of Massachusetts.

This was the first of an annual program allowing a broad range of companies to showcase cleaner technologies. The program will continue to provide grants to recognize the many companies across the Commonwealth that have used toxics use reduction and cleaner technologies while enhancing their firm's competitiveness.

The following report is an in-depth analysis of the cleaner technology demonstrated at Lockheed Martin Defense Systems, Pittsfield, Massachusetts.

We would like to express sincere thanks to John Raschko, Office of Technical Assistance, for his helpful comments and insights in the development of this report.

Notice

This report has been reviewed by the Institute and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Toxics Use Reduction Institute, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

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1.0 INTRODUCTION

Lockheed Martin Defense Systems (LMDS) designs and manufactures a variety of complex, precision aerospace products for the armed forces of the United States and its allies. These products include missile fire control systems, missile and gun turret drives, and of particular interest to this report, combat vehicle transmissions. To ensure product reliability, parts are cleaned thoroughly and frequently throughout the assembly process.

Previously, parts were cleaned using chlorinated solvent vapor degreasers containing the ozone depleting compounds (ODCs) 1,1,1 trichloroethane (also known as trichlor, 1,1,1-TCA, and methyl chloroform) and chlorofluorocarbon-113 (also known as CFC-113, and freon-113). LMDS used thirty-nine vapor degreasers throughout their facility. As recently as 1988, these units used more than 120 tons per year of chlorinated solvents. Due to environmental impacts and increasing economic disincentives, LMDS committed to eliminate their use of ODCs.

Multidisciplinary teams, with members representing each LMDS organization with a stake in the cleaning problem and its resolution, explored alternatives to the vapor degreasing processes. Alternatives were evaluated against a wide range of screening criteria, including life cycle costs, technical and performance measurements, and workplace health and safety.

Because of the diversity of the products at LMDS, no single solution was found to be directly applicable for all process areas. The teams selected aqueous ultrasonic technology as the best core solution for most applications, and tailored the cleaning chemistry, water purification and filtration, rinse/dry equipment, and ultrasonic transducer design and placement to the individual cleaning applications. Nine aqueous systems are now in place, replacing most of the original thirty-nine vapor degreasers enabling a reduction of chlorinated solvent use to less than 1.7 tons in 1995, and 0.04 tons year-to-date as of October 1996. (Note: The LMDS inertial guidance production line still uses vapor degreasers by customer direction.)

For the transmission development laboratory, aqueous ultrasonic cleaning was selected with filtration systems configured to greatly reduce water and detergent consumption by separating waste oil and suspended particles from the cleaning and rinsing baths. Annually, less than one-half drum of waste oil is removed from this system and disposed of as regulated waste. The system allows the cleaning bath life to be extended to one and a half years and the rinse bath to be used as make-up water for the new cleaning bath.

2.0 DESCRIPTION OF LOCKHEED MARTIN DEFENSE SYSTEMS

Lockheed Martin Defense Systems designs, manufactures, and provides repair services and technical support for a variety of complex and precise products for the armed services. For the Navy, these products include, inertial guidance and fire control systems for the Fleet Ballistic Missile System, Aegis Missile Directors, and Phalanx surface ship defense components. For the Army and Marine Corps, products include tracked vehicle transmissions, and turret stabilization and drive systems. The hydromechanical steering transmission used in the Army's Bradley Fighting Vehicle will be the focus of this report.

LMDS's facilities, located in Pittsfield, MA and neighboring towns, were originally occupied by GE's Aerospace Group. In 1993, Martin Marietta acquired the Aerospace businesses from GE, and in 1996, Martin Marietta and Lockheed merged to form Lockheed Martin. Employing more than 1600 people, LMDS is one of Berkshire County's largest industrial employer.

3.0 DESCRIPTION OF TECHNOLOGY

3.1 Hydromechanical Transmission Product Overview

The LMDS hydromechanical transmission ("HMPT") is used in a variety of military tracked vehicles, including the Army's Bradley Fighting Vehicle. Available in power ranges from 500 HP to 1500 HP, the HMPT uses two pairs of ball piston hydraulic pumps and motors to provide an infinite range of output drive ratios to each of the vehicle's treads. By varying the displacement of the ball piston pump, and by controlling the balance of hydraulic and direct gear drive, performance and fuel economy is maximized. The HMPT also provides vehicle steering and braking. LMDS has delivered more than 8000 of these HMPT units and continues to build and repair them, and to design product improvements and new models.

The internals of the HMPT include parts of varying geometries and substrates, including gears, shafts, housings, bushings, bearings and fasteners. Materials include cast iron, a variety of steels, bronze, aluminum, and plastics. Cast, forged and machined parts are used, and surface treatments include electroplating and anodizing.

3.2 Cleaning Requirements

At the Transmission Development Laboratory located at Ordinance Plant (OP-8), engineers and technicians assemble and test product improvements for existing HMPT models, as well as prototype versions of new HMPT models. Also, failed transmissions received from the field are disassembled and analyzed to assess failure causes and modes.

Parts cleaning in this facility poses a range of challenges. New parts received at OP-8 are sometimes coated with preservatives or greases which must be removed prior to assembly. Parts removed from failed transmissions are often contaminated with carbonized oils and metallic particles, which must also be removed to facilitate failure analysis and reassembly.

3.3 Description of Chlorinated Solvent Vapor Degreaser Technology

Previously parts cleaning at OP-8 was accomplished using two chlorinated solvent vapor degreasers. These degreasers were effective at removing the variety of oily contaminants encountered at OP-8.

As illustrated in the process flow diagram (see Figure 1) parts were inspected and, if soils were heavy, hand cleaned using a rag to remove heavy greases and other contaminants. Parts were immersed in a hydrocarbon preclean tank and, if necessary, hand scrubbed with the hydrocarbon cleaner and a brush made of steel (hard substrates), brass, or plastic (more delicate substrates).

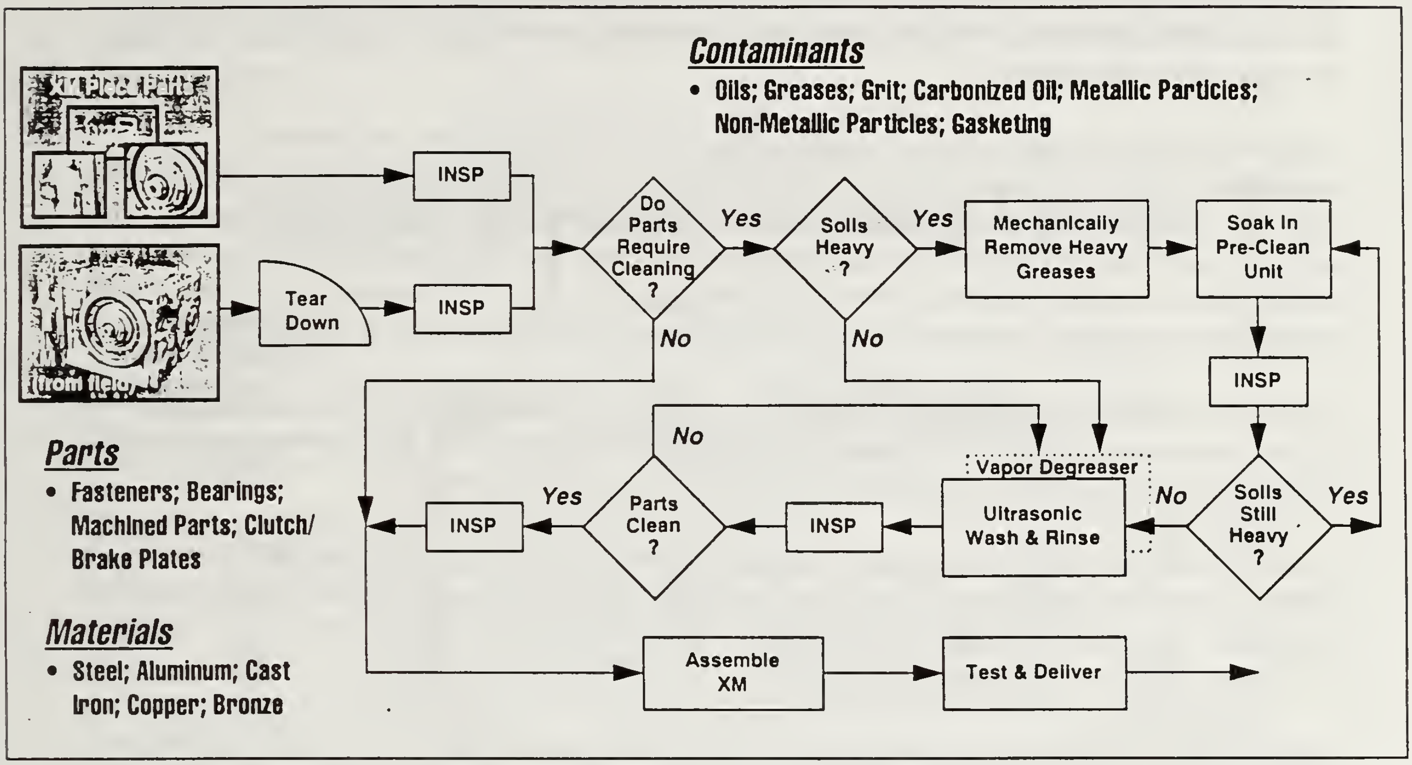

Contaminants
• Oils; Greases; Grit; Carbonized Oil; Metallic Particles; Non-Metallic Particles; Gasketing
(from field)
INSP
Tear Down
INSP
Do Parts Require Cleaning ?
Yes
No
Soils Heavy ?
Yes
No
Mechanically Remove Heavy Greases
Soak In Pre-Clean Unit
INSP
Soils Still Heavy ?
Yes
No
Vapor Degreaser
Ultrasonic Wash & Rinse
INSP
Parts Clean ?
Yes
No
INSP
Parts
• Fasteners; Bearings; Machined Parts; Clutch/ Brake Plates
Materials
• Steel; Aluminum; Cast Iron; Copper; Bronze
Assemble XM
Test & Deliver

Figure 1 - Process Flow Diagram for Parts Cleaning

Parts that had been precleaned and parts that did not require precleaning were then cleaned in the vapor degreaser by lowering them into the vapor zone where ambient temperature parts were brought into contact with the hot solvent vapors, causing the vapors to condense on the surface of the parts. The high rate of liquid flow over the surface of the parts was effective at removing solvent-soluble soils and nonsoluble contaminants such as particulates. Although the chlorinated solvent vapor degreaser was capable of removing heavy greases, the precleaning process discussed above was employed because the volume and composition of these greases would have caused the solvent to become fouled at rapid rate. Each of the two vapor degreasers at OP-8 held about 45 gallons of trichloroethane, which required frequent replenishing due to evaporative losses and drag-out. The tank was emptied and cleaned every three to four months and the spent solvent was disposed of as hazardous waste. In 1992, the last year the vapor degreasers were used at OP-8, 187.5 gallons of 1,1,1 trichloroethane were used.

3.4 Description of Aqueous Ultrasonic Technology

The initial steps of the transmission build and repair process at OP-8 have not been affected by the switch to aqueous ultrasonic cleaning. Parts are still inspected to determine their cleaning needs. However, during the planning process prior to the switch to aqueous ultrasonic cleaning, LMDS re-evaluated their cleaning needs and realized that some parts do not routinely require cleaning. When the vapor degreaser was used all parts were cleaned regardless of their level of cleanliness. Now parts are initially inspected to determine if cleaning is in fact required, reducing the time and resources spent on cleaning.

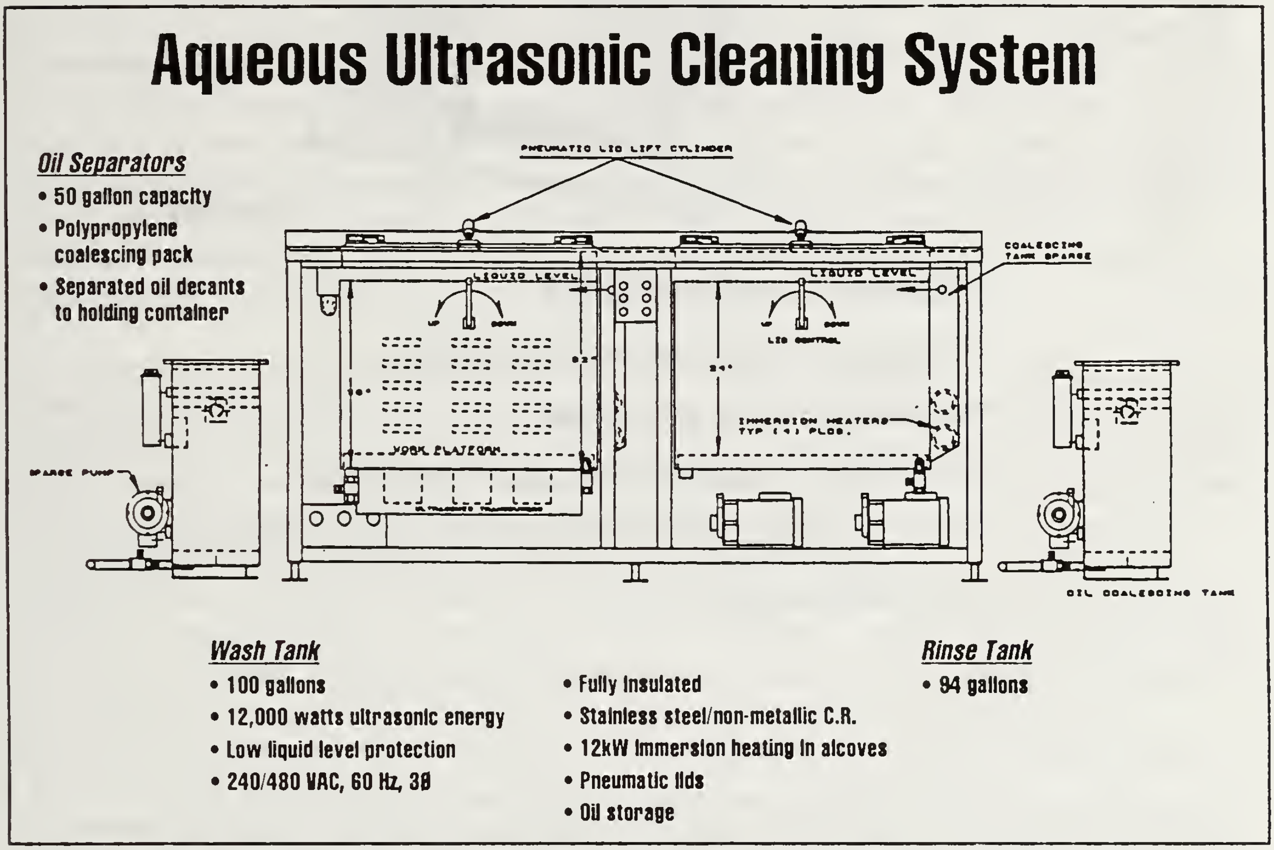
If parts do require cleaning and soils are found to be heavy, the parts are precleaned by handwiping and/or immersion in the hydrocarbon system. These precleaned parts, as well as other parts that do not require precleaning are cleaned and rinsed in the aqueous ultrasonic system. As seen in Figure 1, the process flow using the vapor degreaser and the aqueous ultrasonic cleaner are the same except for the initial decision to clean or not to clean. This decision point was added when the team sought out ways to reduce solvent usage, and also resulted in reduced labor.

Parts to be cleaned in the ultrasonic system are inspected by the operator. Depending on the level of contamination remaining, the operator immerses the part in the wash tank for between one and ten minutes, and then immerses it in the rinse tank for about one minute.

The wash and rinse tanks are housed in a single unit framework (Figure 2). The wash tank has six 2 kW arrays of ultrasonic transducers, three each mounted on the exterior of the bottom and front tank walls. The tank holds one hundred gallons of cleaning solution (5% by weight of Daraclean 212 mixed with tap water) at 150°F.

The rinse tank contains ninety four gallons of water maintained at 165°F. Both tanks are heated with electric immersion heaters. The elevated rinse water temperature heats the parts and results in rapid evaporation when the part is removed, making a drier unit unnecessary. Each tank contains a work rest at its bottom to prevent damage to the bottom of the tank or the transducers. The tank walls are well insulated to keep surface temperatures down and to muffle the harmonics generated by the ultrasonic transducers. Though the cleaner is not a regulated substance, lip vents were installed in each tank to eliminate direct exposure to vapors. At the request of the operators, spray wands were installed on each tank to provide additional mechanical energy. After the system was operating workers determined that the wands were not necessary except for very difficult cleaning problems, involving heavy soils in deep crevices.

The six transducers mounted on the exterior of the front wall and bottom of the cleaning tank generate ultrasonic waves in the bath, which, in turn, cause a phenomena known as *cavitation* in the tank's aqueous solution. Cavitation is the formation of tiny bubbles at the surface of the part. These bubbles implode causing estimated instantaneous pressures of 10,000 psi and temperatures of 10,000°F. This mechanical energy and heat aids in the removal of contaminants from the surface of parts. There are two types of ultrasonic transducers: piezoelectric transducers which consist of ceramic disks that generate ultrasonic waves in the 40 kHz range; and magnetostrictive transducers which consist of excitation coils wrapped around nickel laminations that are silver brazed to a diaphragm. Magnetostrictive transducers operate in the 20 kHz range. Piezoelectric transducers convert alternating electrical energy directly to mechanical energy through use of the piezoelectric effect in which certain materials change dimension when an electric charge is applied to them. Electrical energy within the ultrasonic range of frequencies is supplied to the transducer by the ultrasonic generator. This energy is applied to the piezoelectric element(s) which then vibrate; these vibrations are transferred into the liquid through the radiating plate.



Aqueous Ultrasonic Cleaning System

Oil Separators
- 50 gallon capacity
- Polypropylene coalescing pack
- Separated oil decants to holding container

Wash Tank
- 100 gallons
- 12,000 watts ultrasonic energy
- Low liquid level protection
- 240/480 VAC, 60 Hz, 3Ø

- Fully insulated
- Stainless steel/non-metallic C.R.
- 12kW immersion heating in alcoves
- Pneumatic lids
- Oil storage

Rinse Tank
- 94 gallons

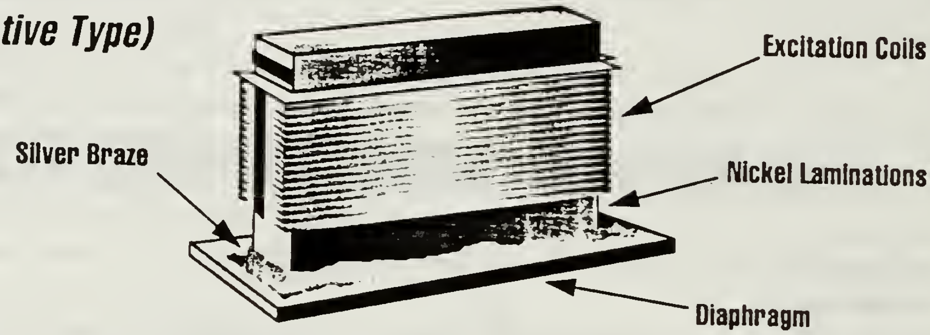
Figure 2

Magnetostrictive transducers (Figure 3), consisting of laminated stacks of nickel-iron metal, are energized in a reversing magnetic field, inducing mechanical vibrations which are transmitted to the radiating plate. Magnetostrictive transducers can, because of their more robust construvtion, operate at higher energy levels than piezoelectric devices, and can deliver more power to the parts tank.

For the OP-8 application, LMDS selected magnetostrictive transducers. The transducers were placed so as to maximize the transfer of energy into the tank, and to make the energy distribution pattern uniform within the tank. The robust design of the transmission parts can tolerate this environment, which is efficient for removing heavy oily soils.

Ultrasonic Transducer

(Magnetostrictive Type)



- **Resistant to mechanical shock**
- **Tolerant of high operating temperatures**
- **Good bond to tank bottom/side**
- **Designed to resonate at its natural frequency**
- **Relatively insensitive to changes in liquid level, physical load**
- **No frequency drift**

Figure 3

The cleaner used in 5% solution in the ultrasonic wash tank is Daraclean 212, produced by W. R. Grace. This slightly alkaline[1] cleaner is amber colored, has a bland odor, and contains no phosphates, silicates, or SARA reportable substances. Daraclean 212 is a modrate foaming alkaline liquid blend of organic surfactants, water conditioners, and organic and inorganic inhibitors designed especially for cleaning operations where a wide range of organic and inorganic soils are encountered.

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[1] In concentrated form the cleaner has a pH of 8.3-8.7.

3.5 Description of 'Closed Loop' Filtration System[2]

Both the wash tank and the rinse tank contain an overflow weir that allow oily wastes to flow from the surface of the wash and rinse baths to coalescing filters where the oily waste passes through a polyethylene mesh cube. The mesh cube attracts smaller droplets of oil and causes them to collect and form larger droplets. When a sufficiently large droplet has formed, the density gradient between the bath and the oil causes the oil to float to the surface of the filter bath. An overflow weir in the coalescing filter allows the oil grouped on the surface of the filter bath to decant to a storage canister.

For the oily waste to properly flow to the storage canister, two parameters need to be controlled: the height of the overflow weir and the rate of flow through the filter. If the weir height or flow rate are too high oily waste is returned to the wash and/or rinse tank. If the weir height is too low water is allowed to pass to the waste oil canister causing it to fill faster. Also, this water increases the volume of waste that needs to be handled as state-regulated oily waste. Operators at LMDS feel that the process of manipulating these two parameters is too problematic and have chosen to use oil absorbing pads on the surface of the tank. When the pads become saturated with oil, usually once a month, they are placed on a drying table where entrapped water is allowed to evaporate prior to disposing of the spent pads as state-regulated oily waste.

In some aqueous cleaning systems a portion of the oil waste may become emulsified in the cleaning bath as a result of the surfactant in the cleaner orienting itself at the interface between the oil droplet and the cleaner bath. Because of the presence of surfactant molecules at the interface, droplets have like charges and therefore repel each other and prevent coalescing. Over time the cleaning bath may become fouled by these emulsified oils. Although coalescing filters are effective on coalescing oils that have been mechanically emulsified, they are not effective at breaking emulsions formed by surfactants. Passing the oily waste through the mesh cube is not enough to dislodge the surfactant from the surface of the droplet, which would be required to get these oils to coalesce.[3] Emulsified oils have not been a problem at LMDS because the cleaner used contains non-emulsifying surfactants. For systems that do contain emulsified oils, ultrafiltration has been proven to be effective at removing these oils and extending the bath life.[4]

In addition to oily wastes, particulate matter suspended in the bath may contaminate the wash or rinse bath. Filtration systems have been designed to remove these suspended contaminants and greatly increase the bath life. Continuous filtration of the wash and rinse baths at LMDS is achieved by two cartridge filters in series. The first cartridge retains any contaminants larger than fifty microns while the second cartridge retains those larger than 10 microns. The filters are replaced every six months. In cleaning baths where emulsified oils are present, fouling of the filter media by these oils may cause the media to foul at a much faster rate. However, in the design specifications for the cleaner chemistry, LMDS stated that the cleaner should not emulsify any hydrocarbon contaminants in order to prevent this problem at the source.

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[2] Realizing that few, if any, systems are entirely 'closed-loop' (i.e., zero emissions), the term is used here to describe a situation where filtration systems are succesfully extending the bath life far beyond what would be expected without filtration.

[3] Magdich, Paula, "Oil-Water Separation Techniques: A Literature Review," Minnesota Technical Assistance Program, University of Minnesota, July 1986.

[4] Underwood, Christopher, Karen Thomas, "Closed Loop Aqueous Cleaning," The Massachusetts Toxics Use Reduction Institute, Technical Report No. 29, 1995.

The filtration unit in combination with the selected cleaning chemistry has allowed LMDS to extend the cleaner and rinse bath lives. This system was expected to maintain the baths for up to a year, but operators observed that after one year's time the baths were not foul and continued to clean effectively. After one and a half years the baths were cleaned even though they did not look particularly dirty. When the wash bath is changed, the contents of the rinse bath are used as make-up for the new wash bath. The tank bottoms from the wash and rinse tanks are removed by the operator and drummed as hazardous waste. The waste consists of metal fines, rubber, and plastic chips as well as other particulate matters.

When the design team was selecting a system, they hoped to come up with an alternative that was environmentally benign to the point where spent cleaner baths.could be discharged to the local publicly owned treatment works (POTW). However, due to the metal fines in the tank bottoms and sensitivity of the local POTW, LMDS determined it would be more realistic to drum the waste (approximately 165 gallons every two years) and dispose of it as state regulated oily waste.

4.0 METHODOLOGY USED TO SELECT, PROCURE AND IMPLEMENT A NEW CLEANING TECHNOLOGY

4.1 Methodology Overview

LMDS made a commitment to eliminate the use of ozone depleting compounds in their manufacturing process because of the increasing economic and regulatory disincentives associated with the use and disposal of these compounds and their environmental impact. Classically companies have solved such problems using a top-down decision making approach, where management dictates a solution based on "expert" recommendation. There are a number of negative implications to this type of problem solving. The problem may not be fully defined without the input and experience of stake holders. Although the expert may be knowledgeable in one area, s/he may not be experienced in all areas pertinent to the problem (e.g. user friendliness of systems). Also, when other stake holders are not involved in the decision making process they do not have ownership in seeing the new system succeed.

4.2 Composition and Application of Multi-Disciplinary Teams

At LMDS, multidisciplinary teams were formed to solve the cleaning problem. Teams were comprised of representatives from all organizations with a stake in the problem and its resolution. Team members worked together to generate and evaluate alternatives to their vapor degreasing processes by utilizing the wide range of expertise of the group.

Each member of the team that was formed to solve the cleaning problem at OP-8 provided different skills and concerns that were necessary for the problem to be resolved properly. OP-8 operators were concerned with the performance and user friendliness of the new system; Engineering addressed use and functionality issues; Quality Assurance insured product quality would not be compromised; Finance/Accounting provided information on the flow of funds and financing; Sourcing determined the best purchase price and facilitated the procurement process; Facilities had a stake in the installation and maintenance needs of the system; Environmental, Safety and Health (ESH) was concerned about the environmental, worker health and safety impact of the new system; and Programs had a stake in production schedules, throughput times, and customer satisfaction.

4.3 Developing Technical Evaluation Criteria

To ensure that the new system would properly address the needs of LMDS, the team generated a list of system requirements that would be used to evaluate alternatives. The requirements were identified in brainstorming sessions where the team discussed issues such as cleanliness needs, installation procedures, operation and maintenance requirements, and environmental, safety and health issues associated with a cleaning system. When the list of requirements was generated, each requirement was rated in order of relative importance (see Table 1; eg: size/footprint was ranked #12 in order of importance). Then the team developed a ranking system that would allow them to use this list of requirements as a tool to measure the effectiveness of an alternative system (Candidate #1, 2, or 3) at meeting a certain requirement relative to other alternative systems being considered. The ranking system involved qualitatively or quantitatively measuring how well an alternative system met a given requirement. When all alternative systems being considered were evaluated for one requirement, they would be given a relative ranking for that requirement (1, 2, or 3; see Table 1). When each requirement was ranked, the rankings were multiplied by the relative rating of each requirement (example: Candidate #2, size/footprint (12), ranked third 12 x 3 = 36). When this weighted ranking was completed, the columns would be added for each candidate and the lowest score would be the best alternative.

4.4 Development of Economic Assessment Criteria

When a firm is considering the purchase of a new piece of equipment, an economic assessment is performed to evaluate the financial impact of the available alternatives. For example, when deciding between two technologies that perform the same task, economic assessment is used with other measures to aid the firm in selecting one alternative over the other. Classically, economic

Table 1
System Requirements and Ranking

Attribute and Relative Ranking	Requirement	Relative Ranking		
		Candidate # 1	Candidate # 2	Candidate # 3
Design and Performance				
Size/footprint (12)	12' x 8' (max)	1	3	2
Soils to be cleaned (2)		1	2	3
- Engine oils	All except carbonized	2	3	1
- Metal particles	All	2	1	3
- Grit	All visible grits			
Cleanliness criteria (3)	Remove visible oils, grits, particles			
Soils removal Efficiency	100% in allotted time			
Cleaning time	Max. immersion time 10 minutes			
Materials to be cleaned:				
- Aluminum	No corrosion, etching, or staining			
- Steel	No rusting etching, or staining			
- Cast iron	No rusting etching, or staining			
Surfaces:				
- Plated	Cleanliness measure			
- Anodized	Cleanliness measure			
Size and form factors				
Lead time				
Installation				
Utilities				
Rigging				
Time to install				
Operator training				
Operation and Maintenance				
Solvent:				
- Availability				
- Disposal				
Tank bottoms				
Tank cleaning frequency				
Operator retraining				
Filter charges				
Filter changes				
Incurred damage (dropped parts)				
Environmental, health, and safety				
Noise				
Surface temperatures				
Fumes/vapors				
Solvent:				
- Odor				
- Toxicity				
- Disposal when spent				
Shock hazards				
PPE				
Permitting				
Record keeping				

assessments only considered factors such as capital equipment costs, operator training costs and material costs. However, a more holistic look at costs associated with the equipment over its useful life, referred to by Lockheed Martin as life cycle cost analysis, allows firms to make more educated decisions for technology selection. When all life cycle cost elements are included in the assessment, they are often significant enough to reverse the outcome of a comparison of two systems which may have been based on only more immediate cost elements.

Life cycle cost analysis was used at LMDS to assess the economics of each candidate system. All of the costs associated with switching to a new cleaning system were identified and divided into two sections: non-recurring costs, such as capital and operator training costs, and recurring costs, such as solvent procurement and disposal costs. The costs for each candidate were then totaled and the least expensive alternative identified. Table 2 lists the cost element that LMDS included in their life cycle cost analysis.

4.5 Equipment Evaluation and Selection

When the requirements ranking process was developed and costs to be included in the economic assessment were identified, LMDS focused their selection process on aqueous and semi-aqueous systems, which include immersion, spray, and tumbler. Other alternative processes were rejected because of the team's dissatisfaction with one or more critical aspects of these alternatives. For example, supercritical CO_2 was not seriously considered because the team felt the technology was not fully developed. Another alternative that was discarded was hydrocarbon cleaning because of the environmental, safety and health concerns regarding the vapors and flammable solvent.

The team narrowed their focus to several aqueous ultrasonic systems. These systems were ranked using the requirements ranking system and economic assessment tool discussed above (Tables 1 and 2). Based on these evaluations, the aqueous ultrasonic wash and rinse system produced by Lewis Corporation was selected. Of the systems evaluated, this system was rated highest by LMDS' requirements ranking system. Procurement costs for the Lewis system are given in Table 3.

4.6 Sources of Technical Assistance

Throughout the process of generating and evaluating alternative cleaning processes the teams at LMDS used the services of a number of government agencies and private firms to gain from their technical expertise and experience. LMDS contacted the Office of Technical Assistance (OTA) and the Toxics Use Reduction Institute (TURI) throughout their planning and implementation processes to discuss and resolve technical issues they encountered. OTA provided the teams with fact sheets that detailed stories of other firms who successfully switched from chlorinated solvent vapor degreasing to aqueous cleaning, including Hyde Tool of Southbridge, MA.

Table 2
Full Cost Analysis

Cost Element	Present System	Candidate#1	Candidate #2	Candidate #3
Non-Recurring Costs:				
Procurement				
Capital				
Selection of best system				
Facility modifications required for installation				
Utilities hook-up				
Rigging				
Removal/disposal of old equipment				
Operator training				
PPE				
System validation				
Permitting				
Recurring Costs (Annualized)				
Solvent procurement and storage				
Filters procurement				
Spent solvent disposal				
Used filters disposal				
Tank bottoms disposal				
Parts cleaning costs				
Depreciation				
Utilities				
Operator training				
Preventive maintenance				
Repairs				
PPE replacement				
Record keeping				
Permitting and fees				
Totals	$\Sigma =$	$\Sigma =$	$\Sigma =$	$\Sigma =$

Table 3
Procurement Costs of Lewis 'Closed-Loop' Aqueous Ultrasonic Cleaning System

Basic System		
	Aqueous ultrasonic cleaning tank	$ 50,765
	Immersion rinse tank	8,325
	Subtotal	**$ 59,090**
Options		
	Oil separation system	$ 8,320
	Pump and filter systems (2)	11,450
	Spray lances (2)	1,100
	Work rests (2)	1,800
	Pneumatic lids (2)	2,400
	Lip vents and exhausts (2)	4,400
	Subtotal	**$ 29,470**
	Total cost of system	**$ 88,560**

Representatives visited TURI and researched alternative processes in the Technology Transfer Center (TTC).[5] While at TURI they visited the Surface Cleaning Lab (SCL) to view alternative cleaning systems. In addition to the technical research done at the TTC, LMDS reviewed literature at a local technical library and the EPA library in Boston.[6]

Within the company, a CFC elimination task force had previously performed an extensive survey of the cleaning industry. The teams used this information to obtain an overview of cleaning alternatives and to determine which alternatives would be appropriate to consider for their process. The LMDS team contacted six vendors identified by this survey and obtained more information.

4.7 Procurement and Installation Process

When the Lewis system was selected, the LMDS Team developed system specifications which outlined the configuration, operational requirements, design and construction requirements, acceptance requirements, and warranty and payment requirements. The procurement process detailed in the specifications required the system to pass three milestones. When the initial design drawings were completed they were to be approved by the LMDS team prior to procurement and fabrication of the parts for the system. After the design drawings were finalized, the operator's manual was completed, and a recommended spare parts list was available, the LMDS team gave a second approval. Once the system was built and tested, the manufacturer was required to demonstrate to LMDS, at Lewis' facility, that the system met the design and performance criteria specified. The system passed these specifications, requiring no modifications, and was delivered to LMDS.

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[5] The TTC is a library at TURI with holdings that focus on pollution prevention technologies, worker health and safety issues, and policy matters related to pollution prevention.

[6] LMDS has time-sharing at the EPA library.

Seamless introduction of the new system into the laboratory was necessary to prevent interruption of the process. This was achieved by involving the team in the planning and facilitating of the installation and transfer processes. The key operator at OP-8 visited the vendor's facility where he was trained in the operation and maintenance of the system, which allowed him to then train the other operators. Also, prior to removing the vapor degreaser the team insured that the ultrasonic system was operating to their satisfaction and all operators were comfortable operating it.

Procurement costs for the Lewis system were approximately $89,000. This included the basic system, comprised of the aqueous ultrasonic cleaning tank, immersion rinse tank and options, including oil separation system, pump and filter systems (2), spray lances (2), work rests (2), pneumatic lids (2), lip vents and exhausts (2). It should be recognized that equipment manufacturers can custom-build systems in price ranges to suit the customer's needs.

5.0 TOXICS USE REDUCTION ASSESSMENT

5.1 Environmental Assessment

When LMDS made the commitment to eliminate their use of ODCs, and hence switched to aqueous-based cleaning, they greatly reduced the environmental impact of their cleaning processes. Facility-wide, LMDS reduced their use of 1,1,1 TCA and CFC-113 from 125 tons in 1988 to less than 1.7 tons in 1995. At OP-8 the use of ODCs was reduced from 2,074 pounds in 1992 to zero pounds today. Approximately 1,140 pounds of the 1,1,1 trichloroethane used at OP-8 in 1992 were emitted to the atmosphere and approximately 934 pounds were removed by hazardous waste handlers.

As mentioned earlier, when the ultrasonic cleaning bath was drained and cleaned after 1.5 years, the bath was drummed and handled as state-regulated oily waste. The spent bath is handled this way because the tank bottom contains metal, plastic, and rubber particles. The waste oil from the coalescing filters is removed by a waste hauler.

Though water was not used to clean parts in the old system, there was significant water used in the cooling system of the vapor degreasers. The vapor degreasers at OP-8 used approximately two million gallons of water per year to circulate through cooling coils at the top of the vapor zones to reduce fugitive solvent emissions by promoting condensation. Removing the vapor degreasers eliminated this water use entirely, as well as the subsequent discharge to POTW.

5.2 Occupational Health and Safety Assessment

The switch to aqueous ultrasonic cleaning resulted in the elimination of worker exposure to the suspected carcinogen 1,1,1 trichloroethane (1,1,1-TCA). Health effects associated with short term inhalation of levels of 1,1,1-TCA above 900 parts per million (ppm) include dizziness, mental confusion, drowsiness, loss of coordination, unconsciousness, and skin irritation and rashes. Repeated or prolonged exposure to levels of 1,1,1 TCA above 450 ppm may irritate the eyes, result in dry, fractured skin, dizziness, mental confusion, slow response time, and generally reversible liver and kidney damage.[7] Workers at Lockheed Martin Defense Systems are no longer at risk of being exposed to these health hazards.

It was a top priority of the team that the system selected to replace the vapor degreaser pose no new worker health and safety hazards. Other alternative systems being considered were eliminated early in the process due to the hazards they posed. For example, the hydrocarbon system, as mentioned earlier, was rejected because of the health effects associated with the solvent's vapors and flammability. When the aqueous system was selected, the specifications drafted by the team called for added safety features such as additional insulation to prevent burn hazards and dampen acoustic harmonics generated by the ultrasonic transducers.

5.3 Economic Benefits

Facility-wide, LMDS saves $497,000 in solvent procurement costs, $17,500 in waste disposal costs, and $65,000 in air emissions permitting (310 CMR 702 was eliminated) and record keeping costs, and tens of thousands of dollars in water and sewer costs annually as a result of their toxics use reduction effort. In the transmission assembly and repair process at OP-8 LMDS saves $3,450 in water and sewer costs annually (two million gallons at $1.77 per thousand gallons).

6.0 OTHER ISSUES AFFECTING IMPLEMENTATION

When firms change equipment or materials used in a manufacturing process several barriers must be overcome before these changes are effectively integrated including workplace/operator acceptance and technical acceptance. There are a number of variables that affect the magnitude of these barriers such as how accepting of change operators are and what resources are available to assist firms in overcoming technical barriers.

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[7] Sittig, Marshall, Handbook of Toxic and Hazardous Chemicals and Carcinogens, Third Edition, Vol. 2, Noyes Publications, Park Ridge, NJ, 1991.

6.1 Workplace/Operator Acceptance

Although aqueous ultrasonic cleaning has been proven to be effective, any change to a process may not always be well received by operators. The implementation of aqueous cleaning required a change in operator work habits since the process may not, in all situations, be as effective or simple as chlorinated solvent vapor degreasing. The health hazards associated with exposure to chlorinated solvents is often minimized by operators. However, many workers take solace in the elimination of this exposure and most workers acknowledge the fact that some of these solvents are partially responsible for the depletion of the ozone layer.

No solvent exists as a drop-in replacement for 1,1,1-TCA and CFC-113, that are also environmentally friendly and pose no worker health or safety hazards. Although operators report that such a solvent would be the ideal solution to their cleaning problem, they are aware that all options were explored due to their constant involvement with the problem solving process. Because operators were involved in the problem solving process, they were invested in the solution.

6.2 Cleaning Chemistry

Selecting the proper aqueous cleaning formulation is accomplished by identifying the substrates being cleaned, the contaminants that need to be removed, and the type of system in which the formulation will be used. Certain cleaners are more effective at removing a given contaminant and may be less aggressive on certain substrates than other formulations. The type of cleaning system being used is important because certain formulations are more effective in some types of systems and certain cleaning systems are more effective at cleaning than others, therefore requiring less 'work' from the formulation. The parts cleaned at OP-8 are durable mechanical parts, which allowed the team to direct a larger amount of ultrasonic energy into the tank without causing damage to the parts. This large amount of mechanical energy reduces the amount of cleaning power needed from the formulation.

For a firm with cleaning needs similar to those at OP-8, selecting a cleaner may be easier than for a facility which is cleaning parts prior to plating or cleaning printed wire boards. Parts at OP-8 need to pass only a visual cleanliness test, but parts to be plated or wire boards to be soldered need to be precision cleaned so that microscopic contaminants are not left undetected on a part. The slightest contamination may result in unsuccessful plating or soldering. Therefore, the cleaning requirements of formulations for firms requiring a higher level of cleanliness are much greater than those at OP-8.

Often equipment vendors offer their own formulations. When this is not the case, there are numerous vendors of cleaner formulations that will work with a client to determine which formulation is best for their application. As mentioned earlier in section 3.5, when LMDS wrote the system specifications for the vendor, they outlined the requirements of the cleaning chemistry. Following these specifications the vendor found a formulation that met the cleaning needs at OP-8.

6.3 Technical Issues

The aqueous ultrasonic cleaning system now employed at OP-8 is quite different from their previous system. Often aqueous cleaning systems contain a water deionizing system to prevent hard water stains from appearing on parts after rinsing and drying. Hard water stains are a function of the water quality in a given region and the substrate being rinsed. If the water is inherently hard and the substrates, because of their nature, rinse poorly, then hard water staining may be a problem. This may be exacerbated at high temperatures because salts are more ionic. Neither water stains nor drying are problems at OP-8, since the water is not hard and the high temperature rinse promotes drying.

In addition to direct technological modifications that may need to be made for a new system to be introduced into a manufacturing process, there are often process flow modifications that are required. As discussed in Section 2.4, when OP-8 switched to aqueous cleaning they re-evaluated the need to clean all parts, and found that many did not need further cleaning. This saved time and resources previously spent degreasing parts that did not require cleaning. With both the vapor degreaser and the aqueous ultrasonic cleaning system, some subassemblies are completely disassembled prior to cleaning. This was necessary with the vapor degreaser to insure that contaminants were not trapped in blind spots such as spaces between ball bearings. With the aqueous system, additional subassemblies are disassembled to insure that water and/or contaminants are not entrapped which may later interfere with the functioning of the transmission.

6.4 Previous Successes with Related Technologies

Experiences at Hyde Tool and other similar firms that eliminated vapor degreasing reaffirmed the viability of aqueous cleaning of metal parts. Based on those tools and others' successes, LMDS was able to move confidently forward with aqueous cleaning technology.

Prior to the ODC elimination project, LMDS had success using shared stake holder decision making to design and implement a clean technology innovation at their facility. LMDS wanted to modify a metal treating and plating process that uses chromic acid to make it a zero-discharge process. They employed shared stake holder decision making and successfully achieved this goal. The team was able to learn from the successes and difficulties encountered by this earlier group and gain reassurance that this type of decision making process could succeed at LMDS.

7.0 OPPORTUNITIES FOR TRANSFER OF TECHNOLOGY

Aqueous cleaning is an effective replacement for chlorinated solvent vapor degreasing in many applications. The type of cleaning process and cleaning formulation selected is dependent on the cleaning needs of a given process and product. Although LMDS selected ultrasonic cleaning, another facility may find that some other process, such as spray washers or immersion baths, may provide the required level of cleanliness for their parts. Likewise, the cleaning solution should be selected specific to the contaminants and cleaning needs of a particular facility.

Often when firms switch from vapor degreasing to aqueous cleaning they are faced with the treatment or disposal of an aqueous waste. This issue may be alleviated by installing filtration systems such as the coalescing and cartridge system employed by LMDS, or membrane ultrafiltration systems. These systems not only further decrease the environmental impact of a firm's manufacturing process, they also decrease operating costs and hence shorten the payback period of a new aqueous system.[8]

The cleaning formulation selected should be chosen specifically for the contaminants and substrates encountered at a given facility. The chemistry used by LMDS is effective at removing their contaminants, but it may not work as well on different soils and substrates. The cleaner vendors will usually offer assistance in selecting the most appropriate formulation for a specific application. The Surface Cleaning Laboratory at TURI will perform surface cleaning evaluations to help firms determine the best cleaning process and chemistry for their application.

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[8] Underwood, Christopher, Karen Thomas, "Closed Loop Aqueous Cleaning," The Massachusetts Toxics Use Reduction Institute, Technical Report No. 29, 1995.